HYDRO - ELECTRIC DEVELOPMENT
ON THE
WEST BRANCH OF THE PENOBSCOT RIVER
IN MAINE

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PROPOSED

HYDRO-ELECTRIC DEVELOPMENT ON THE WEST BRANCH OF THE PENOBSCOT RIVER IN MAINE

A THESIS

PRESENTED TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

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AND

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FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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PROPOSED

HYDRO-ELECTRIC DEVELOPMENT ON THE WEST BRANCH OF THE PENOBSCOT RIVER.

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INTRODUCTION.

Nature daily creates millions of horse power by the streams and rivulets coursing down mountain and hillside. Since time without record water power has been utilized by man, and yet in comparison with the supply the amount that is consumed to-day is infinitesimally small.

The idea of water power is generally associated with a large river or stream, huge dam, giant penstock and massive water wheels, enormous generators and long transmission lines, and with imposing blocks of securities.

Before the advent of electric transmission it was generally thought to be impracticable to utilize any natural water powers except those which furnish a large volume and within reasonably close proximity to commercial centers, where the power could be marketed to advantage. Now, however, it is found advantageous to harness even small streams, provided sufficient flow can be obtained and enough head is available. It is reasonable to believe that the interest which is being aroused in the development of hydraulic power is destined to increase, especially in mountainous countries.

Hence, having in mind the foregoing opportunities for enlarging the use of water power and the ideas

that are associated therewith, we (Arthur C. Lill, Raymond L. Walsh and Joseph S. Ehrman, as students of Armour Institute of Technology) have chosen for thesis work the Design of a Hydro-Electric Power Plant on the West Branch of the Penobscot River in Maine.

It is the sincere effort of the writers not to make this investigation of a final character on which the feasibility of the project may be based, but rather of a character which will give the student a fair idea of what must be included in a report of this nature. The less important details will not be worked out, but plants which are similar in nature and which are operating successfully will be referred to at various times and the details taken from them.

WATER POWER.

Fall available but undeveloped.

Of the fall of over 800 feet on the West Branch of the Penobscot River, between Midway and Seeboomook, 185 feet is utilized in the plants of the Great Northern Paper Co. at Millinocket, Dolly and East Millinocket.

The valley of the West Branch of the Penobscot, from Twrin Lakes to Chesuncook Lake, is rugged and picturesque. The total fall in this distance of 25 miles, measured from the sill of the deep gates of Chesuncook dam to the elevation of the sill of the deep gates of North Twrin dam, is 444 feet. Chesuncook dam will hold a head of about 22 feet, and the level of the lower lakes may be raised 25 feet by North Twrin dam. Of this 444 feet, 310 feet occurs in the first 10 miles and 240 feet in the first 5 1/2 miles below Chesuncook dam. A number of abrupt falls occur in this stretch of the river.

Water Power.

Between Big Eddy and Ripogenus (see Plate 1) dam, at the foot of Ripogenus Lake, a distance of 2.4 miles, the fall is 214 feet. In this stretch the river is a torrent, flowing through ledges with almost vertical sides, 40 to 75 feet high. In many places it is

very narrow and affords excellent dam sites. The drainage area at the outlet of Pipogenus Lake is 1410 square miles. Under natural conditions this should provide a extreme low-water flow of perhaps 240 second feet, which would give under a fall of 214 feet, 5836 gross horse power. Under fully developed storage, as indicated, on p.208 Water Supply Paper 279, this could be increased upward to nearly 23,000 horse power.

A dam will be built at .12 miles down stream from the Ripogenus dam. The power house will be located at a distance of 2.28 miles from the dam. The water will be led, by means of steel riveted and wooden stave pipes, to the power house. In this manner the net value of the 214 foot head will be made use of, with a minimum expenditure for dam construction, Whenever power has been developed from a high head, it has been found that it is more economical to construct a smaller dam in connection with a pipe line, than it is to construct a huge dam without a pipe line, and make use of the same head. Therefore in this development the former construction was chosen.

The power which will be developed is 4084 net horse power, assuming an 80 per cent. efficiency. The

amount of water which will be used by the water wheels is 240 second feet, which is the lowest value of flow in the river at this point.

At Millinocket, a distance of about 15 miles southeast from the outlet of Ripogenus Lake, a gaging station has been established by the Great Northern Paper Co. since Jan. 11, 1901. The discharge of the West Branch of the Penobscot River at this point is measured by considering the flow through the water wheels of this company, and the flow over a dam on the Penobscot, at the outlet of Quakish Lake, a little over a mile from the mill site on the Millinocket Stream. Millinocket stream enters the Penobscot about 4.5 miles below Quakish Lake. The wheels which measure the water were rated at Holyoke, Mass., before being placed in position.

The records of the discharge at Millinocket are under the personal supervision of Mr. Ferguson, who is the engineer for the company. All data has been carefully kept and is rated as being excellent.

The following table shows the maximum daily discharge of the West Branch of the Penobscot River at Millinocket. (Taken from Water Supply Paper 279, p.131)

West Branch of Penobscot
at Millinocket
Drainage Area
1880 square miles

Dates	Second feet	Second ft.per sq. mile
Apr., 1900	------	------
Apr., 1901	24,000	12.8
Mar., 1902	18,000	9.7
Apr., 1902	18,000	19.7
Apr., 1903	24,200	12.9
May, 1904	15,000	8.0
May, 1906	21,000	11.2
May, 1907	23,000	12.2
Apr., 1909	21,000	11.2
May, 1909	21,000	11.2
Sept., 1909	8,500	4.5

The following table shows the minimum mean monthly flow at Millinocket. See Water Supply Paper 279, p.136.

West Branch of Penobscot River at Millinocket.
(Drainage area, 1880 square miles)

Period	Mean discharge Second feet	Mean discharge Second ft.per square mile	Period	Mean discharge Second feet	Mean discharge Second ft.per square mile	Period	Mean discharge Sec- 2nd ond ft.	Mean discharge ft.per sq. mile
1904			1905			1908		
Feb.22-27	320	0.17	Dec.20-26	351	0.19	(a)		
Jan. 1-31	328	.17	Jan., 1906	403	.21			
Jan. to Mar.	407	.22	Nov., 1905-					
Oct., 1903-			Jan., 1906	415	.22			
Mar., 1904	471	.25	Nov., 1905-					
June, 1903-			Apr., 1906	646	.34			
May, 1904	1560	.83						

a Records October to December not available.

Calculations.

At Millinocket.

Drainage area - 1880 square miles.

Maximum daily discharge Apr., 1903, 24200 second feet.

Minimum monthly discharge Feb.22-27, 1904, 320 second feet.

The distance between Millinocket and the outlet of Ripogenus Lake is about 15 miles. We will assume drainage conditions at this point on the west branch the same as at Millinocket.

At outlet of Ripogenus Lake:

Drainage area - 1410 square miles.

Maximum daily discharge is equal to

$$\frac{1410}{1880} \times 24200 = \frac{3412200}{188} = 18150 \text{ second feet}$$

Minimum monthly discharge is equal to

$$\frac{1410}{1880} \times 320 = \frac{45120}{188} = 240 \text{ second feet}$$

Horse Power Developed.

Elevation of tail water - - 667.33

" " crest of dam - 870.68

Head lost due to friction in pipe line = 16.12 feet.

Therefore available head

870.68 - 667.33 = 203.35

The available head is considered as acting from crest of dam to tail water.

Hence the effective head h

$$h = 203.35 - 16.12 = 187.23 \text{ feet.}$$

$$\text{Gross H.P.} = \frac{w\ h\ q}{550}$$

where w = weight per cu.ft. water

h = effective head

q = minimum discharge in second feet.

Therefore

$$\text{H.P.} = \frac{62.5 \times 187.23 \times 240}{550}$$

= 5105 gross horse power.

Assume water wheels to have an efficiency of 80 per cent.

Hence net horse power 4084.

In K.W. this power is equal to 3050.

DAM.

The dam is to extend completely across the river, at a point where the river is narrow and the banks high. The location of the dam is 2.28 miles up stream from the power house, or about .12 miles down stream from the crest of the Ripogenus dam. The banks and the bed of the river are assumed to be of solid rock. The height of dam and elevation of base was determined from a longitudinal profile of the stream. See map, Plate 1. These values, as taken, are not absolutely correct; but a transverse profile of the stream could not be obtained. The maximum flow of the stream is about 18200 second feet.

The dam proper is of the gravity type, designed to withstand sliding and overturning. It is 59.5 feet wide at the base, 12 feet at the crest and has a height of 55.68 feet. (See Drawing, Plate 2.) The total length of dam is a spillway section and it measures about 120 feet.

The spillway has a vertical face up stream, and the down stream face is shaped to an ogee curve, which is a combination of a parabola and an arc of a circle. The parabola has been calculated mathematically.

(See calculation.) The pressures at the toe and heel of the dam were found to have a value of 9730 and 3350 pounds respectively, indicating that the design errs on the side of safety.

Constructing the dam to a height as given in the foregoing, will back the water up, during high water season, to elevation 883.33, which is the elevation of the surface of the water in Ripogenus Lake.

Calculations:

From profile - elevation of base of dam = 815.0

Maximum discharge of stream = 18200 second feet.

Width of stream as scaled from map = 120 feet.

Amount of water which turbines use = 240 second feet.

Therefore, second feet of water wasted is equal to

$$18200 - 240 = 17960$$

Francis' weir formula $Q = 3.33 b H^{3/2}$

(See Merriman Hydraulics)

where b = width of dam,
H = head above crest of dam,
Q = maximum amount of wasted water.

therefore $17960 = 3.33 \times 120 \times H^{3/2}$

or $H^{3/2} = 45$

$H = 12.65$ feet.

Hence elevation of crest = 883.33 - 12.65 = 870.68

Then height of dam is equal to

870.68 - 815 = 55.68 feet.

Formula for calculating ogee curve:

$x^2 = 2 p y$ is the formula of a parabola.

$2p = 1.98 H$ where H as calculated in the foregoing is 12.65 feet.

$2p = 1.98 \times 12.65$

therefore $p = 14.3$.

Hence with the aid of this equation the ogee curve can be laid out (See plate of dam).

Pressure Calculations.

Resultant pressure = 282000 lbs. = V

Eccentricity = 3 feet 6 in. = e

Area of base = 43.1 sq.ft. = A

Formula for unit pressure when acting force is eccentric.

$$P = \frac{V}{A}\left(1 \pm \frac{6c}{A}\right)$$

Hence

P = 9730 lbs. at toe of dam.

P = 3350 lbs. at heel of dam.

INTAKE SYSTEM.

The intake system is to be located a short distance above the dam and it is to be made rectangular in form, consisting of retaining walls. The walls measure 37 feet in height, 6 feet in width at the top and 21 feet at the base. (See drawing, Plate 2.) The top of the intake walls is at elevation 887. The inside dimensions of the intake are 13 feet by 21.5 feet. (See drawing, Plate 3.) The elevation of low water was taken as 870.68.

In designing the intake system the aim was to give it sufficient capacity. It has been made deep and wide, and the pipes where they enter the intake, and which carry the water to the power house, are well submerged, so as to prevent any possibility of their drawing air. The elevation of the center line of the penstock where it enters the intake is at elevation 855. The velocity of the water in the forebay is about 1.43 feet per sec.

Between the two walls which run parallel to the longer dimensions of the rectangle (See Plate 3) there is placed a concrete reinforced beam. This beam is for the purpose of withstanding the reaction of two head gates which control the water which enters into the

pipes leading to the power house. The gate openings measure 14 feet by 6 feet and they are separated by a 1 foot concrete pier. The pier rises from the bottom of the intake, which is at elevation 850, and extends up to the beam. The beam is 19 feet deep, measured from the top of the walls, 2 feet thick at this point, and 3 feet where the gates rest against it.

Calculations.

Design of retaining section for intake system.

Foundation - rock.

Elevation high water - 883.33

" top retaining Section - 887

Wt. concrete per cu.ft. = 150 lbs.

" water " " = 62.5 lbs.

Required:

(1) Investigation of assumed sections of retaining walls at following elevations:

El. 850 - 860 - 870 - 880.

(2) To determine limits of middle third and points of application of resultant pressure for reservoir when empty and full (See drawing).

(3) To draw limits of middle third and points of application of resultant pressure (See drawing).

(1)

Section 1. El. 880.

Total water pressure = $1/2\ w\ h^2 = P$

where

w = wt per cu.ft. water

h = head of water behind wall

P = total water pressure

h = 3.33 feet

Therefore P = 346 lbs.

In calculating the weight of concrete for any particular section, 1 foot along length of wall is considered.

In assuming the width of wall at the different elevations, it has been taken as a fraction part of the head of water at this elevation.

At elevation 880 the width of wall theoretically should be very small but due to construction difficulties it is assumed as 6 feet.

Therefore wt. of concrete = 6 x 7 x 1 x 150

= 6300 lbs.

Section 2. Elev. 870.

$p = w\ h$ = 62.5 x 13.33

= 834.5 lbs.

Therefore $P = \left(\frac{834.5 + 2083}{2}\right) 10 = 5214$ lbs.

Assume section .6 head of water

Therefore width = .6 x 13.33 = 7.99 feet

= 8 feet

Wt. of concrete = $\left(\frac{8 + 6}{2}\right)$ 10 x 150 = 10500 lbs.

Section 3. Elev. 860.

p = 62.5 x 23.33 = 1460 lbs.

Therefore $P = \left(\frac{1460 + 834.5}{2}\right) 10 = 1147.2$

Assume width section .6 head water

Therefore width = .6 x 23.33 = 13.998

= 14 feet

Wt. of Concrete = $\left(\frac{8 + 14}{2}\right)$ 10 x 150 = 16500 lbs.

Section 4. Elev. 850.

p = 62.5 x 33.33 = 2082 lbs.

$P = \left(\frac{2082 + 1460}{2}\right) 10 = 17710$ lbs.

Assume section .63 head of water

Therefore width = 21 feet

Wt. of concrete = $\left(\frac{14 + 21}{2}\right)$ 10 x 150

= 26220 lbs.

Pressures at toe and heel of retaining wall.

$P = V/A \left(1 + \frac{6\ e}{A}\right)$ pressure at toe

$P = V/A \left(1 - \frac{6\ e}{A}\right)$ pressure at heel

V = resultant force = 69500 lbs.

e = eccentricity = 2.33 feet

A = area of base = 18 x 1 = 18 sq. ft.

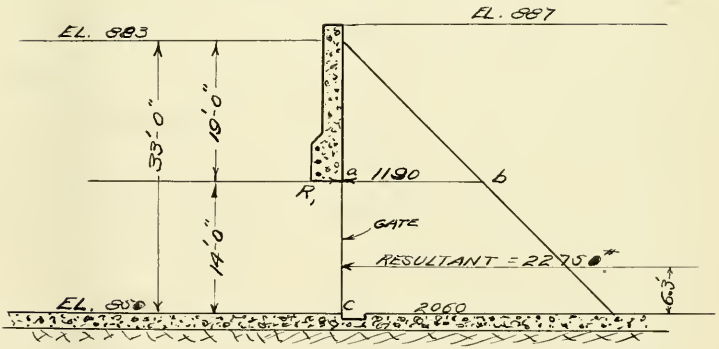
Hence

P at toe = 6694 lbs.

P at heel = 1026 lbs.

From values of pressures the wall is safe.

Design of concrete reinforced beam:



Water pressure at end of gate p = w h

p = 19 x 62.5

= 1190 lbs.

Water pressure at bottom of gate

p = 33 x 62.5 = 2060 lbs.

Resultant pressure on gate acts at center of gravity of trapezoid a b c d

c g = 6.3 feet

Resultant pressure = $(\frac{1190 + 2060}{2})$ 14

= 22750 lbs.

Reaction of gate, R, at a

R. = $\frac{22750 \times 6.3}{14}$ = 10240 lbs.

Consider beam as a uniformly loaded simple beam.

Therefore maximum bending

moment M = $\frac{w l^2}{8}$

l = 13 feet length of beam

w = 10240 lbs. load per foot of beam

Hence

M = $\frac{10240 \times (13)^2}{8}$ = 216200 ft. lbs.

= 2594400 in lb.

Formulas taken from concrete design

$$b d^2 = \frac{6 M}{fc}$$

where b = breadth of beam

d = depth " "

fc = allowable stress in concrete

Therefore $bd^2 = \frac{2594400 \times 6}{600}$ = 25944

Assume b = 24"

then d = 33"

Using an approximate formula

$$fc = \frac{16}{3} fs P$$

Where fs = allowable stress in steel

p = ratio of the area of steel to area of beam section.

Solving for P

$$p = \frac{fc \times 3}{16\ fs} = \frac{600 \times 3}{16 \times 12000} = .0094$$

but p = A/bd

where A = area of steel in sq.in.

Therefore A = .0094 x 792

= 7.44 sq.in.

The rods which will give sufficient steel area are 1 1/4 in. round rods spaced 4 in. apart. (Area = 7.36 sq. in.)

Head Gates and Racks.

The intake system has two head gates which control the water entering the penstock leading to the turbines. These gates are each 14 feet by 6 feet in section, and are to be built of selected Georgia hard pine with slides, guides, trucks and hoisting apparatus, so that they may be hoisted by hand. Provision has been made on the top of the walls of the intake for the placing of operating machinery. The water through the gates has a velocity of 1.43 feet per second.

Trash racks, which stop all refuse which is in the water, from passing through the gates into the penstock, are placed in the intake. The racks are built up on bars and I beams which are set into the walls. (See drawing, Plate 3). The spacing and size of the I-beams was not figured for this system but were taken from a similar design in Mead's Water Power Engineering, p.540. The rack is made up of bars 3 in. by 1/4 in., spaced 2 inches between, giving the water through them a velocity of 2 feet per second.

PENSTOCK.

The water is to be carried from the intake to the surge tank through two 5 ft. 6 in. pipes and from the transverse receiver of the surge tank to the power house, through four 2 ft. steel riveted pipes, each of these pipes being 500 feet long. The total length of pipe line is about 12144 feet. The length of pipe which connects the intake with the surge tank shall be of steel riveted pipe for the first mile, and of wooden stave pipe for the remaining length. (See Plate 3.)

The total friction head lost as figured with friction constants taken from Hughes and Safford Hydraulics is 16.12 feet. The water in the pipes was assumed to have a velocity of 5 feet per second. It is well to know that, when constructing the penstock, allowance must be made for contraction and expansion due to varying temperature. It has been found that the movement of the penstock due to expansion and contraction amounts to several inches. A means of overcoming this is to insert at various intervals along the pipe line plate steel expansion joints.

Calculation of size of pipe.

Total quantity of water - 240 second feet.

From Hughes and Safford, p.329.

Friction factor for steel pipe 1.5 per 1000 feet of pipe,
" " " douglas fir 2 years old

1.2 feet per 1000 feet of pipe.

Assume length steel pipe 5280 feet.

" " of wooden stave 6864 feet.

Therefore

5280 x 1.15 = 7.92

6864 x 1.2 = 8.20

16.12 feet total friction head.

SURGE TANK.

The stand pipe or surge tank is to be inserted into the pipe line, between the power house and the intake. It will be located at a distance of about 500 feet from the power house, the elevation of its base being 680. The water from the intake flows through two five and one-half foot steel riveted pipes into the transverse receiver of the surge tank. From this transverse receiver, which is 8 feet in diameter, the water flows to the turbines through 4 steel 2 foot pipes. Above the receiver, and at the required height, is mounted a tank 56 feet high and 30 feet in diameter. This tank is connected to the transverse receiver by a vertical pipe 6 feet in diameter through which the water flows from the tank, when a supply of energy is needed. The water in the standpipe is kept from freezing by the circulation of hot air in the space between the pipe and the lagging, the heat being supplied by steam from a heating plant located at the foot of the pipe.

The function of the surge tank is two-fold: (1) to act as a relief valve in case of excess pressures in the penstock; (2) to furnish a supply of energy to take care of sudden increases of load while the water is

accelerating, and to dissipate the excess kinetic energy in the moving water column at time of sudden drop in load. For these purposes it should be of ample diameter and be placed as close to the turbine as possible. For a complete discussion of the theory and the determination of the range of fluctuation of water level see Meads' Water Power Engineering, p.458.

The design of this surge tankwwas taken from bulletin number 1625 issued by Allis Chalmers Company of Chicago. For details of standpipe see drawing, Plate 4.

Calculations.

Calculation of maximum head fluctuation:

$$Y = \frac{A\,l}{F\,g}\,(v_1 - v_o)$$

Where y = maximum head fluctuation neglecting governor action,

A = cross sectional area of penstock in sq.ft.

l = length of penstock,

F = cross sectional area of standpipe in sq.ft.

g = acceleration due to gravity in feet per second,

v_1 = velocity in the penstock required for new load,

v_o = velocity in penstock at the instant of gate change.

Number wheels 4.

Horse power developed 4084 efficiency = 8070.

Head (effective) = 137 feet.

Total Q = 240 second feet.

q = discharge per wheel = 60 sec.ft.

v_1 = 5 ft. per sec.

height of penstock = 12500 ft.

Provide for a change in load, from full load to three-fourths full load.

Hence, three-fourths full load = 3063 horse power,

$$\therefore q = \frac{3063 \times 550}{62.5 \times 187} = 144 \text{ sec.ft.},$$

from H.P. = $\frac{62.5 \times h \times q}{550}$

$$\therefore v_o = \frac{q}{A} = \frac{144}{48} = 3 \text{ ft. per sec.}$$

$$A = \frac{2}{4} \times 97 \times \overline{5.5}^2 = 48 \text{ sq.ft.}$$

Diameter of surge tank = 30 ft.

$$\therefore F = H \times \frac{\overline{30}^2}{4} = 707 \text{ sq.ft.}$$

Substituting we have:

$$Y = \frac{48 \times 12500}{707 \times 32.15} (5-3) = 10.28 \text{ ft.},$$

which is maximum departure from head.

TAIL RACE AND DRAFT TUBES.

The power house will be built on contour 680 and as close to the shore line of the stream as possible. Then the tail race will extend from the power house out to the stream and will be made, at least, as wide as the power house. The enclosing walls, which will be ordinary retaining sections, have not been designed, because the data used in designing this plant was very meager, and, also, the design of a retaining section is a very simple matter for the engineer.

The race will be excavated so that its bottom will be at the elevation of the bed of the stream. By constructing the tail race in this manner it will contain a few feet of dead water before the turbines are put into operation, and as soon as the water is discharged from the turbines it will push or displace the dead water in the race and thus prevent a loss of head. For instance, suppose the bottom of the race is on a level with the water in the main stream into which the tail race discharges, when the turbines are started the water in the race would rise in proportion to width of race and quantity of water flowing therein, and thus reduce the working head. For want of proper depth and width of race, three to four feet of working head have often been lost.

The water which is discharged from the turbines will be carried to the tail race, through draft tubes. Below the turbines for a short distance the draft tubes are vertical, but upon entering the tail race they will have about a 5 per cent. slope. At the turbines they have a diameter of 2.8 feet and where they leave the power house they become 6 feet in diameter, giving the water a velocity of 8.1 and 2.1 feet per second at the respective sections. The center lines of the draft tubes at the tail race will be about 2 feet below low water mark, or at elevation 665.

POWER STATION.

The power plant is located on the West branch of the Penobscot River about 2.28 miles from the dam, the location of which has been previously given. The power station is to be built on the South bank of the river, as close to the water's edge as it is practical to do so.

The substructure and floors are of reinforced concrete and the superstructure is of brick, with a slate roof supported by steel trusses. The dimensions of the building are 186 1/2 ft. long, 59 ft. 3 in. wide and ft. high from the main floor, which is on a level with the ground to the highest point of the roof.

The main floor contains the four main generators and turbines, turbine governors, two motor-driven exciter set, storage battery, and low tension K_2 switches. Repair shop, office and lavatory are also on main floor. The transformer room, which runs the full length of the building, is also on the main floor and is separated from the generator room by a concrete wall, which carries the L.T. bus bars. A narrow gauge track extends the length of the transformer room for the purpose of conveying transformers to and from the repair shop. Space was allowed at the South end of the building for the future installation of another main unit of the same size as the four to be installed initially.

Directly above the transformer room is the 1st gallery floor, which is of reinforced concrete supported by steel I-beams. This floor extends the full length of the building and across the South end. In the center of the gallery is situated the switchboard. On the North half of the gallery floor are the L.T. H_3 oil switches, and on the South half are the H.T.H_3 oil switches. The section of the first gallery which extends across the South end of the building is divided into two parts by a brick wall. The inner section contains three H.T.H_3 feeder oil switches, while the outer section contains the lightning arrester equipment.

At a height of 16 ft. above the 1st gallery floor is the second gallery floor of similar construction, which carries the H.T. busbar compartments. The second gallery also extends the length of the building and across the South end directly above the feeder switches.

The outgoing lines, which are three in number, are led out through outlets at the South end of the building just above the lightning arresters.

Water for the turbines enters the building by 4 penstocks, one for each turbine. The penstocks enter

the building 4 ft. below the main floor and are supported in concrete beds. The water after leaving the turbine falls vertically down the draft tube a distance of 14 ft. 3 in. and then flows along a gradual slope of 1 to 20 to the tail water. Each turbine has a separate tail water exit tunnel.

A general description of the layout of the plant is as follows: The power is generated by the turbines, which are direct-connected to the alternators. The electrical energy from the generators is delivered through cables to disconnect knife switches and K_2 oil switches and thence to the low tension transfer buses. By means of these disconnect switches and K_2 switches it is possible to connect any alternator with any bank of transformers, which arrangement gives an absolutely flexible system. For the details of this arrangement see the wiring diagram of the station. From the high-tension side of the transformers the current is taken through disconnect knife switches to the H_3, 66000 volt oil switches and thence to the high tension busbars. From here the power goes out through disconnect switches and H_3-66000 volt oil switches to three feeder circuits in parallel, which lead to Bangor, a distance of 60 miles.

HYDRAULIC APPARATUS.

The main turbine units are of the horizontal Francis type, made by S. Morgan Smith & Co., of 1020 H.P. capacity at 400 R.P.M., operating under a off lead of 185 ft. The turbines are mounted on concrete foundations, which rise 2 ft. above the level of the main floor. Each turbine is equipped with a Type Q Lombard Governor for speed regulation.

It was decided to use 4 turbines of equal capacity in the initial installation and allow room for 1 more for future growth. The average daily load on the station is about 2200 H.P., with a max. load of 3600 H.P. So the capacity of the turbines with full gate opening is nearly twice the output of the generators at average load.

The Francis type of turbine was chosen for the work because of the better inherent regulation and efficiency as compared with the impulse type of turbine.

ELECTRICAL APPARATUS.

The four main generators are each horizontal 1000 H.P. 2300 v. 3 phase 60 cycle, 400 R.P.M. direct connected to the turbine shafts. The are of the revolving field type and will carry 50% overload continuously without undue heating.

Excitation for the generators is furnished by two motor driven 30 K.W. 125 v. direct current generators, and a storage battery of 60 K.W. Hr. capacity. The size of the exciters was based on a 1.5% excitation. The two exciters are of ample capacity to furnish the necessary exciting current for the four generators when they are operating at full load. The storage battery is for use in case of a breakdown of one of the exciters or for starting the plant after everything has been shut down, in which case there would be no means of starting the motor-driven exciters.

The transformers are located on the main floor in a room which extends the entire length of the building on the West side. They are each 300 K.W. single phase 2300 v. 66000 v. and are cooled by water taken from the penstocks by small branch pipes. The transformers are delta connected on both the low-tension and high-tension sides. The wiring and switching is so arranged that any bank of transformers can be connected to any generator, which arrangement has been previously described. These transformers are capable of carrying 25% overload without injury.

On the inner wall of the transformer room the low-tension bus-bars are located. They are concealed in

concrete compartments and are spaced 15 in. apart. These bus-bars are of copper and of rectangular cross-section, The current density was taken as 1000 amp. per sq.in., giving a cross section of

$$\frac{750}{1000} = .75 \text{ sq.in.}$$

which is sufficient to carry the current when all four generators are operating at full load.

The switchboard is of the bench board remote control type and is constructed of natural slate mounted upon an angle iron frame. The total length of the board is about 16 ft. It includes four A.C. generator panels, one blank generator panel, and three exciter panels.

All switching is accomplished by means of remote control solenoid operated K_2 switches and motor operated H_3 oil switches. The switchboard is located in the center of the first gallery overlooking the generator room.

The H_3 oil switches are all located on the 1st gallery. On the North half are the 2300 v. H_3 switches, and on the South half the 66000 v. H_3 switches. Behind each 66000 v. switch is a concrete compartment extending up to the second gallery for the high tension leads from the switch to the high-tension bus-bars.

The high tension bus-bars are located on the second gallery in concrete compartments, and are placed 3 1/2 ft. apart. They are of tubular cross-section and were figured for a current density of 500 amp. per sq.in. Assuming an inside diameter of .5 inch,

$$(R^2 - (.25)^2) = \frac{50}{500}$$

$$R = \frac{297}{3.14}$$

$$R = .304$$

which gives an outside diameter of .608". To make the bus-bars a little more rigid it was decided to use an outside diameter of .75".

LIGHTNING ARRESTERS.

The purposes for which the lightning arresters are installed are:

1. To protect the station from outside disturbance.
2. To prevent the spread of disturbance which might occur on the line.

It was decided to use the aluminum disc type of lightning arrester with horn-gaps and choke-coils. The choke-coils are mounted on the inner wall of the lightning arrester room and the horn-gaps and arresters

are connected on the line side of the choke-coils. There are three sets of arresters, one for each outgoing line, and four cells in each set. An arrangement is provided for the charging of the cells.

The lightning arresters are located at the extreme South end of the building on the second floor just below the wall outlets for the feeder circuits.

TRANSMISSION LINE.

There are numerous factors which enter into the design of a transmission line, and in this design the reliability of service and safety were considered more than economy.

The line will consist of one tower line 60 miles in length, carrying three circuits in parallel. The upper circuit will be used to deliver power in the winter time and serve as a ground wire for lightning protection in the summer time. As a transmission line in this part of the country is subject to violent storms in the winter, it was thought best to design the line so that each circuit would be capable of transmitting the total power without undue loss.

From a comparison of the costs of copper and aluminum and their relative weights it was decided that a saving would be effected in the first cost and also in the transportation cost by using aluminum. The use of aluminum necessitates a conductor of larger diameter, but ~~has~~ this has an advantage in that an increase in size of conductor decreases the corona loss.

In calculating the transmission line the economic drop method was used. The assumptions which are necessary in this method were made to agree as nearly as possible with present practice. The equations used in the calculations, the values of the various factors, and the notation is as follows:-

E = voltage at generating station - 66000 v.

P = power in kilowatts at generating station - 4000 K.W.

L_1 = length of line in miles, i.e. length of single conductor - 60 miles.

K_1 = resistance in ohms per mile of conductor having one circular mil cross section - 85,000.

K_2 = weight in pounds per mile of conductor having one circular mil cross section - 0.0048 lbs.

c_1 = cost of energy in dollars per kilowatt-year at generating station - $10.

c_2 = cost of conductor in dollars per pound $ .27.

p_2 = interest rate on cost of line conductors $ .09

x = loss in terms of impressed quantities.

f = frequency = 60 cycle.

$$x = -\frac{3}{4} x \frac{K}{E^2 c_1} + \frac{1}{4E^2 c_1}\sqrt{9K^2 + 12E^2 c_1 K}$$

Area of each conductor:

$$s = \frac{1}{2}\left(\frac{1000P}{E^2} K_1 \frac{2L_1}{x}\right)$$

$$K = 1000\, p_2 c_2 K_1 K_2 4 L_1^2$$

Charging current per phase

$$I_c = 2n\, f\, E\, C \times 10^{-6}$$

The results of the calculations are as follows:

Size of wire - No.0000 B & S.

Kind " wire - Aluminum, 19 strans.

Distance between wires - 72".

Line loss - 4.71%.

Line capacity per wire - .954 microforod.

" inductance " " - .1088 henrys.

Charging current - 13.75 amp.

Line regulation full load - 6.4%.

Towers of windmill type spaced at an average distance of 400 ft. To determine the height of the tower it was first necessary to know the sag of the conductors. In calculating the sag the following notation and equations were used:-

S_1 = span in feet - 400 ft.

W = weight of conductor and ice in pounds per foot - .828 lbs.

W_r = resultant of W and wind pressure in pounds per foot - 2.08 lbs.

A = cross sectional area of conductor in sq.in. = 0.1745.

T = maximum allowable tension in the conductor = 14000 x .1745 = 2443.

t = 0^o 72^o temperature in degrees F, above minimum (40^o F).

k = temperature coefficient of linear expansion per degree F = 0.0000128.

E_1 = stretch modulus of elasticity in pound-inch units = 9,000,000.

L_s = length of single span of strung CABLE at the minimum temperature in feet.

L_w = length of unstressed single span of cable at minimum temperature.

$$L_s = S_1 + \frac{S_1^3 Wr^2}{24(T)^2}$$

$$L_w = \frac{L_s}{1 + \frac{T}{AE_1}}$$

$$D^3 - \frac{3S_1}{8}(L_w(1 + kt) - S_1)\, D = \frac{3\, S_1^3 L_w Wr}{64\, A\, E_1}$$

$$\text{Vertical sag} = D_1 = \frac{W}{W_r} \times D.$$

The following results were obtained:-

Vertical sag = 7.3 ft.
Minimum allowable distance between wire and ground - 125 in.
Height of tower - 40 ft.

ESTIMATE OF COST.

The following figures on the cost of the plant are only approximate, being taken from available data on similar installations now in operation.

From figures obtained in the Electrical World 1910 and Data from the Standard Hand Book cost of the building was estimated at $6.25 1 K.W.

$$4000 \times \frac{746}{1000} \times 6.25 = \$18,700.$$

The Electrical World 1910 gives a cost of $11.00 1 H.P. for generators.

$$4000 \times \$11.00 = \$44000.$$

The cost of transformers is given as $6.25 1 K.W. There are 12 trans. of 300 K.W. capacity each.

12 x 300 x 6.25 = $22,500.

Tables by Cary Hutchinson in the Standard Handbook give the cost of turbines and governors at .915 of the cost of generators and transformers.

.915 x 66,500 = $61,000.

Hutchinson's tables in the St.H.B. give the cost of switchboard and wiring as .21 x cost of generators and transformers.

.21 x 66,500 = $14,000.

Data on installation of similar transmission lines gives a cost of $2200 per mile.

2200 x 60 = $132,000.

Data on mixing, placing concrete and constructing dam:

Required number cu.yd. = 8000

Cost per cu.yd. $7.40 See Gillette on cost data.

∴ Estimate of total cost of dam = 8000 x 7.40

= $59,200.

Data on mixing, placing concrete and constructing of retaining wall sections:

Required number cu.yds. cobcrete 2000.

Cost per cu.yd. $1.25 (See Gillette Cost Data.

∴ Estimate of cost = 2000 x 1.25

= $2500.

Data on construction of penstocks gives the cost of wooden penstocks at $1800 1 mile and $8000 per mile for stell.

1.4 x 1800 = 2520

1.0 x 8000 = 8000

Total $10520

Allowing 15% for engineering and miscellaneous expenses, brings the total cost of the project to

365,000 x 1.15 = $410,000.

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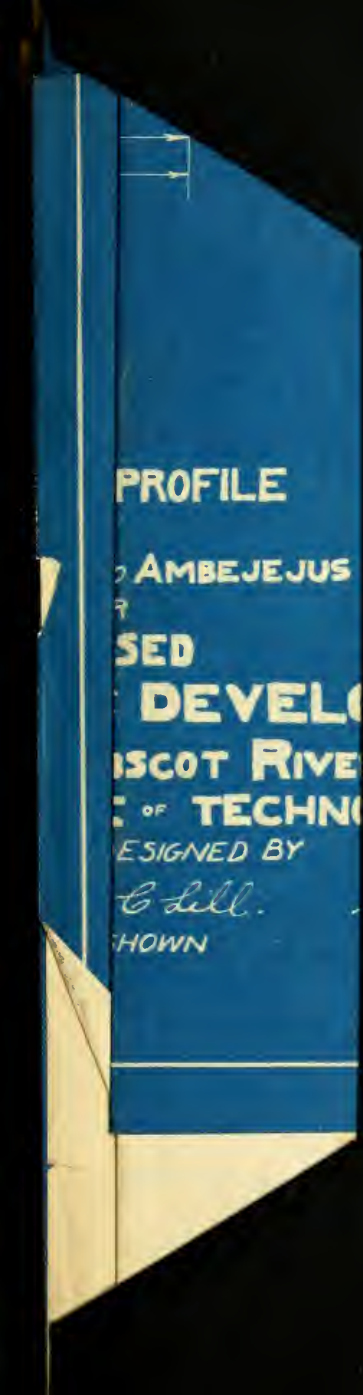
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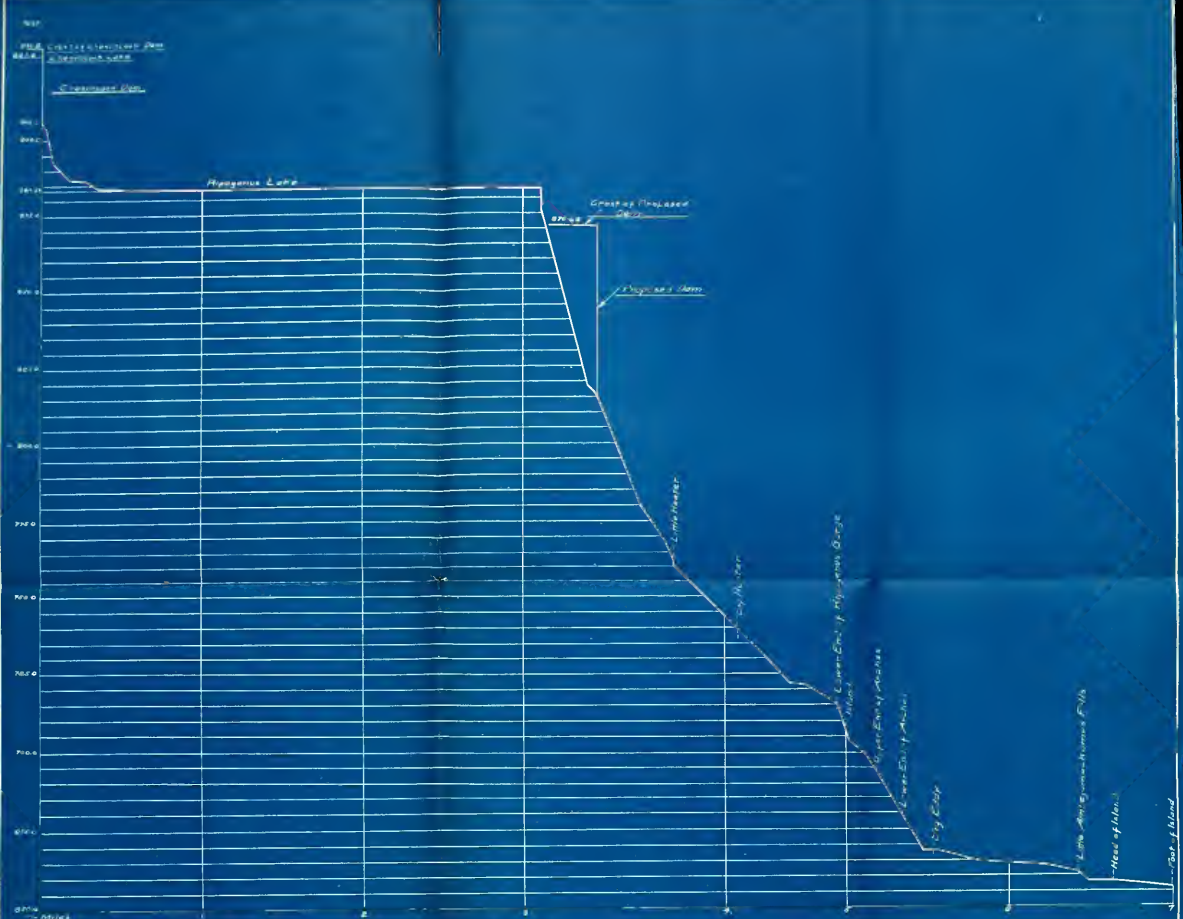


Note: Elevations of Flood Marks are on a datum during 1913 and water Stages from those of original Levels. Flood Elevs are as obtained after time of Survey - 1913.

Note: For Full Details see Water-Supply Paper 337 Plate XIII-A

Scale 1/62500

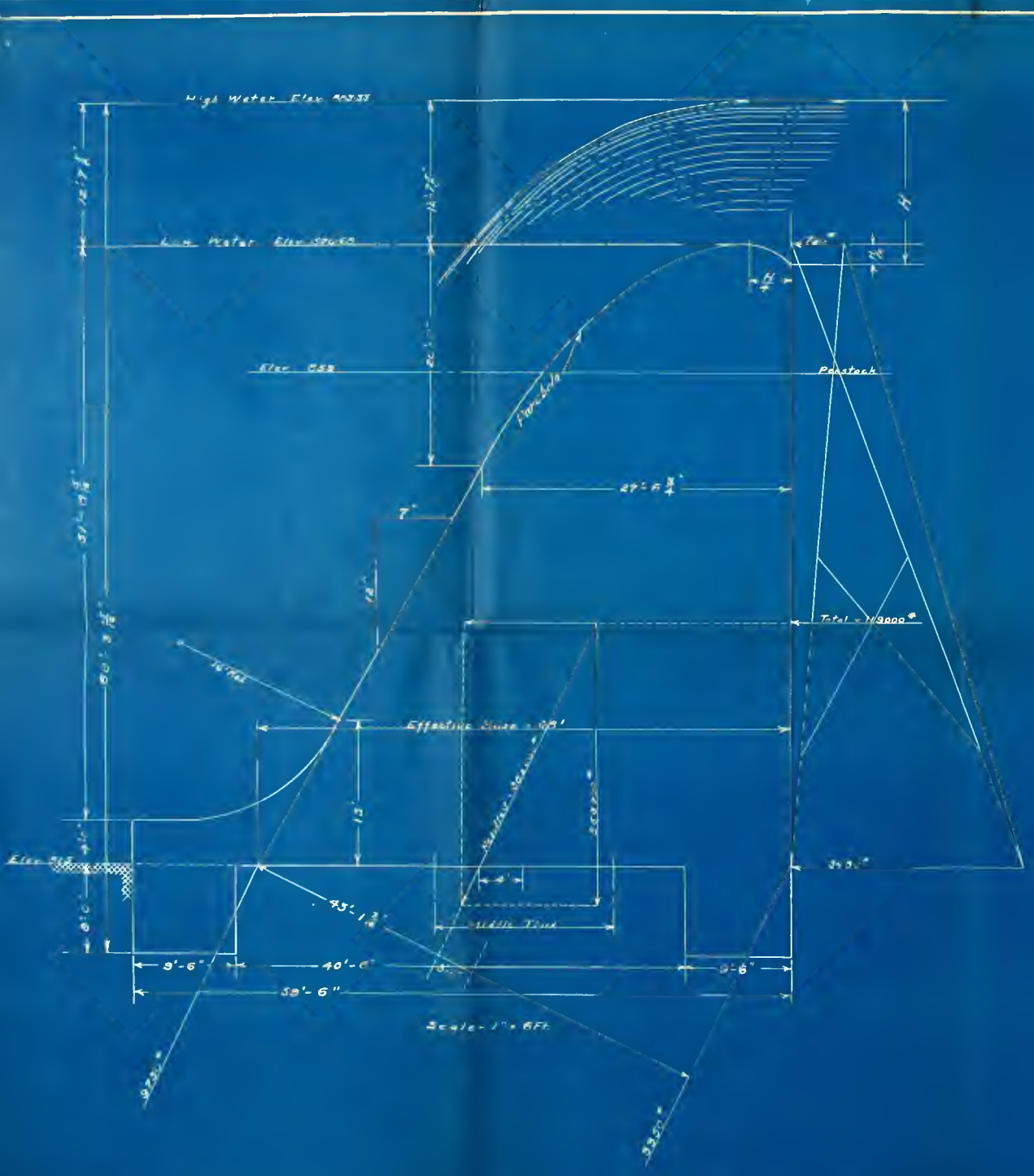
Contour Interval on land = 20 Ft. Datum in most low land

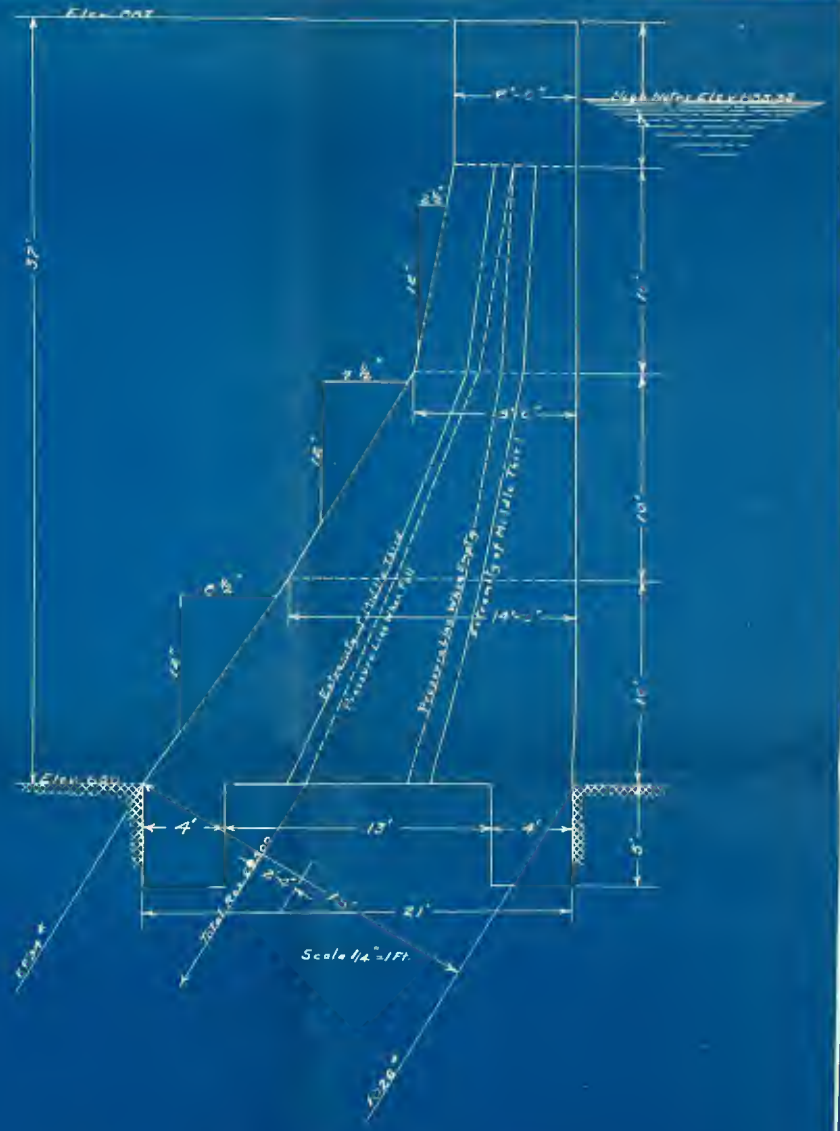
PLAN AND PROFILE
OF
CHESUNCOOK LAKE TO AMBEJEJUS LAKE
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE.
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN AND DESIGNED BY

SCALE AS SHOWN

MAY 23, 1913

CHICAGO, ILL.





DAM

FOR

PROPOSED

HYDRO-ELECTRIC DEVELOPMENT

WEST BRANCH PENOBSCOT RIVER, MAINE.

ARMOUR INSTITUTE OF TECHNOLOGY

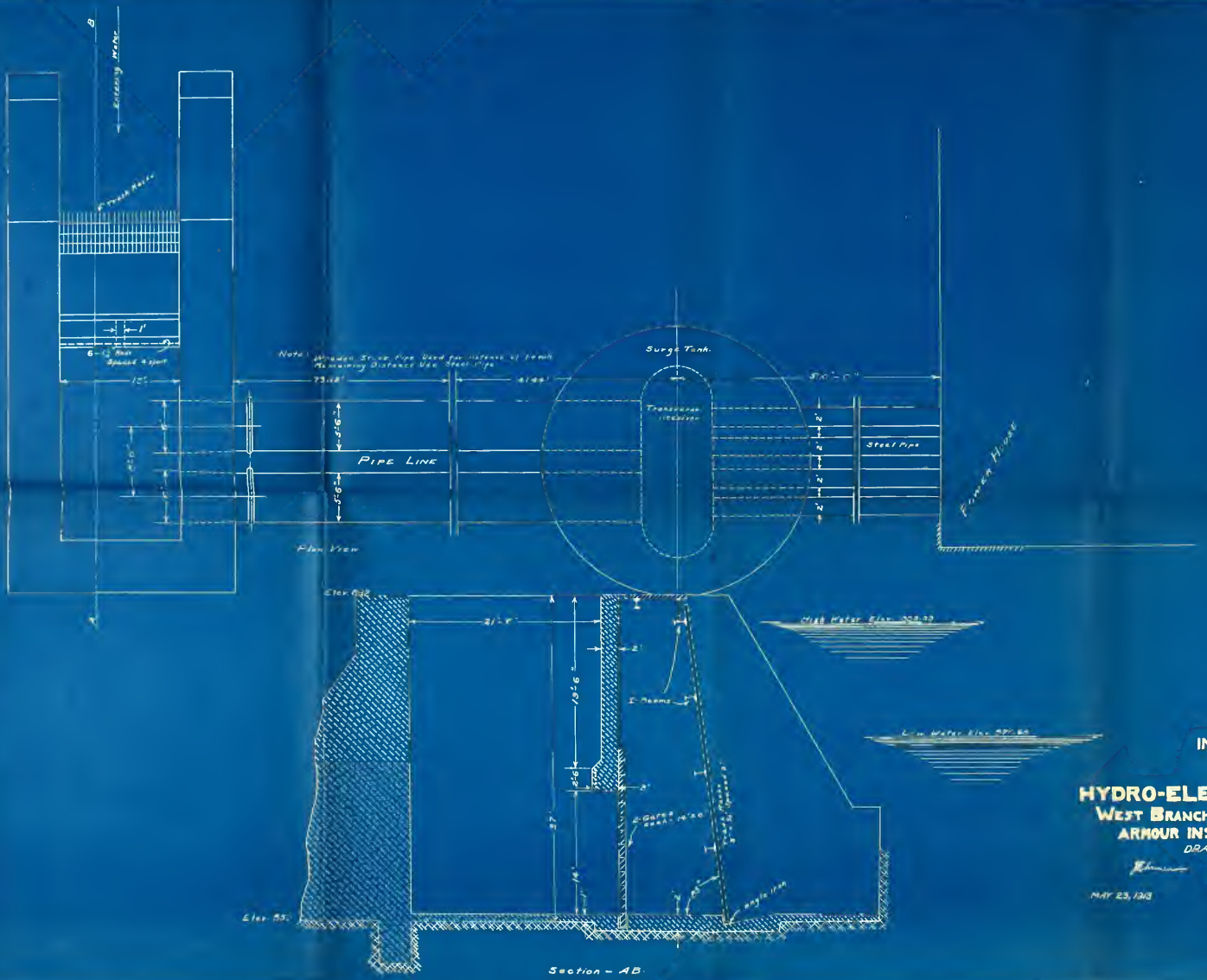
DRAWN AND DESIGNED BY

Arthur C Lill

SCALE 1 = 5FT+4FT

MAY 23, 1913

CHICAGO, ILL.



INTAKE SYSTEM
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE.
ARMOUR INSTITUTE OF TECHNOLOGY

DRAWN AND DESIGNED BY

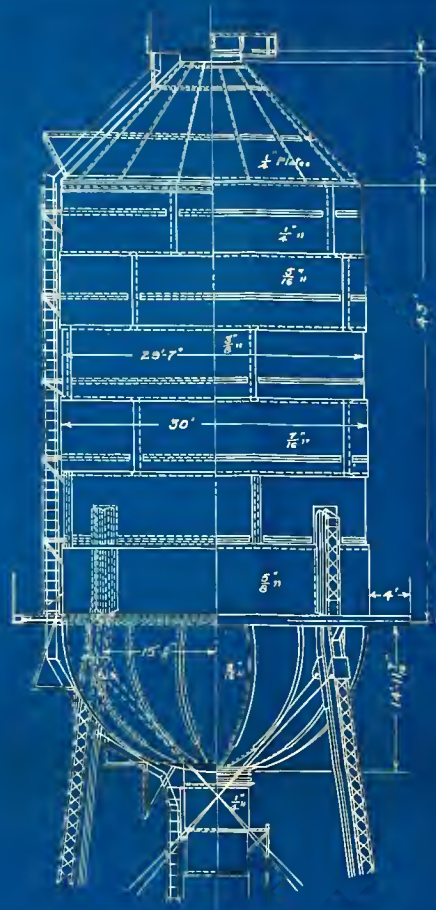
Arthur C. Dill.

SCALE 1/8"=1 FT.

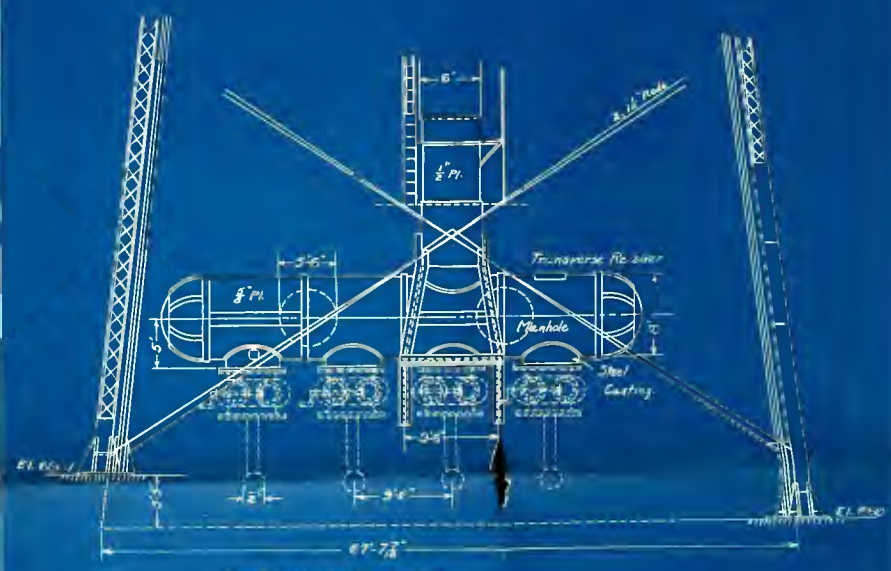
MAY 23, 1913

CHICAGO, ILL.

Surge Tank and Tower



Surge Tank



Cross Receiver at base of Tower

SURGE TANK
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE.
ARMOUR INSTITUTE OF TECHNOLOGY

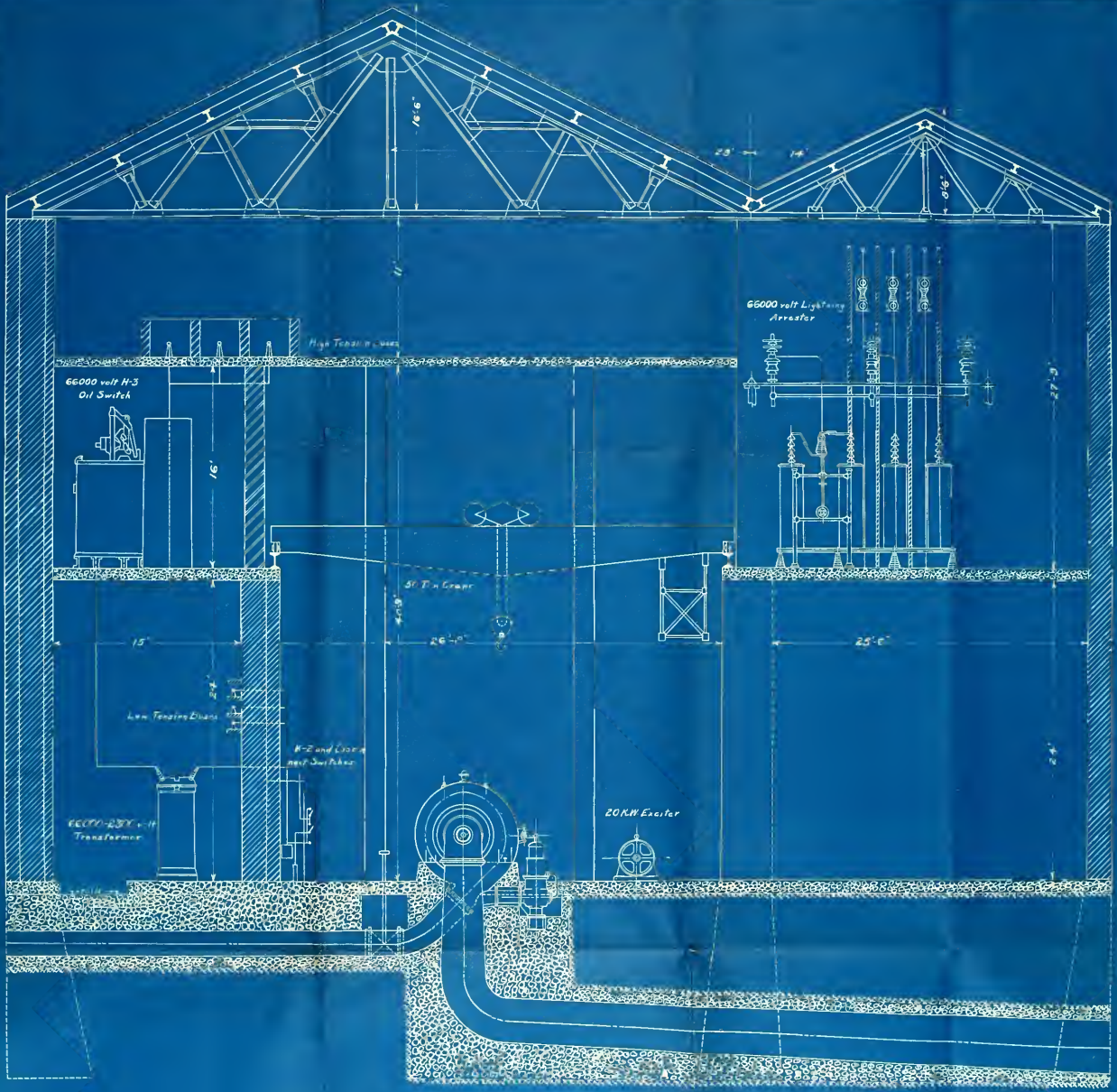
DRAWN AND DESIGNED BY

Arthur C. Lee

SCALE 1" = 12FT = 1FT.

MAY 23, 1913

CHICAGO, ILL.



END ELEVATION
OF
POWER HOUSE
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE.
ARMOUR INSTITUTE OF TECHNOLOGY

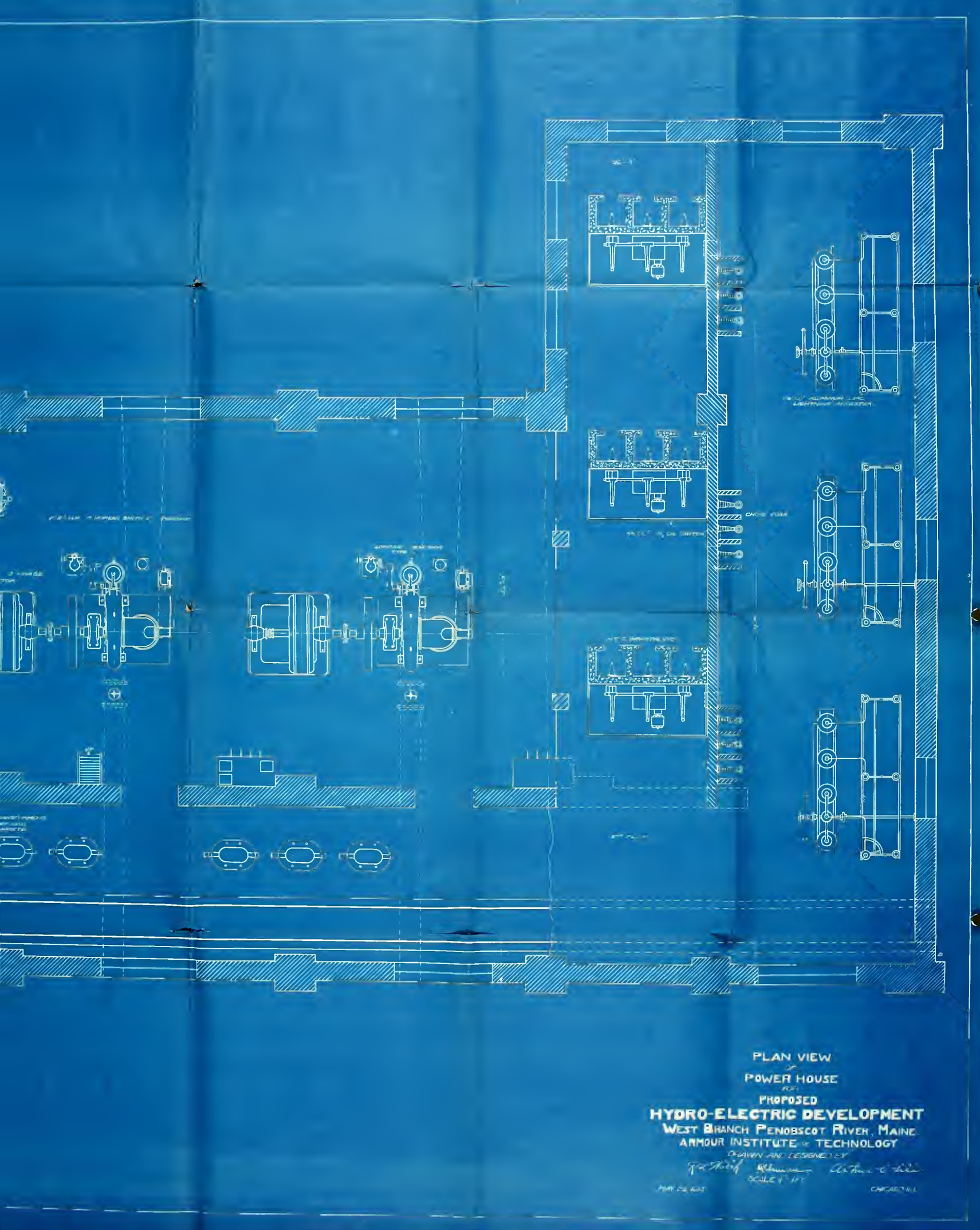
DRAWN AND DESIGNED BY

Clifford C. Bell

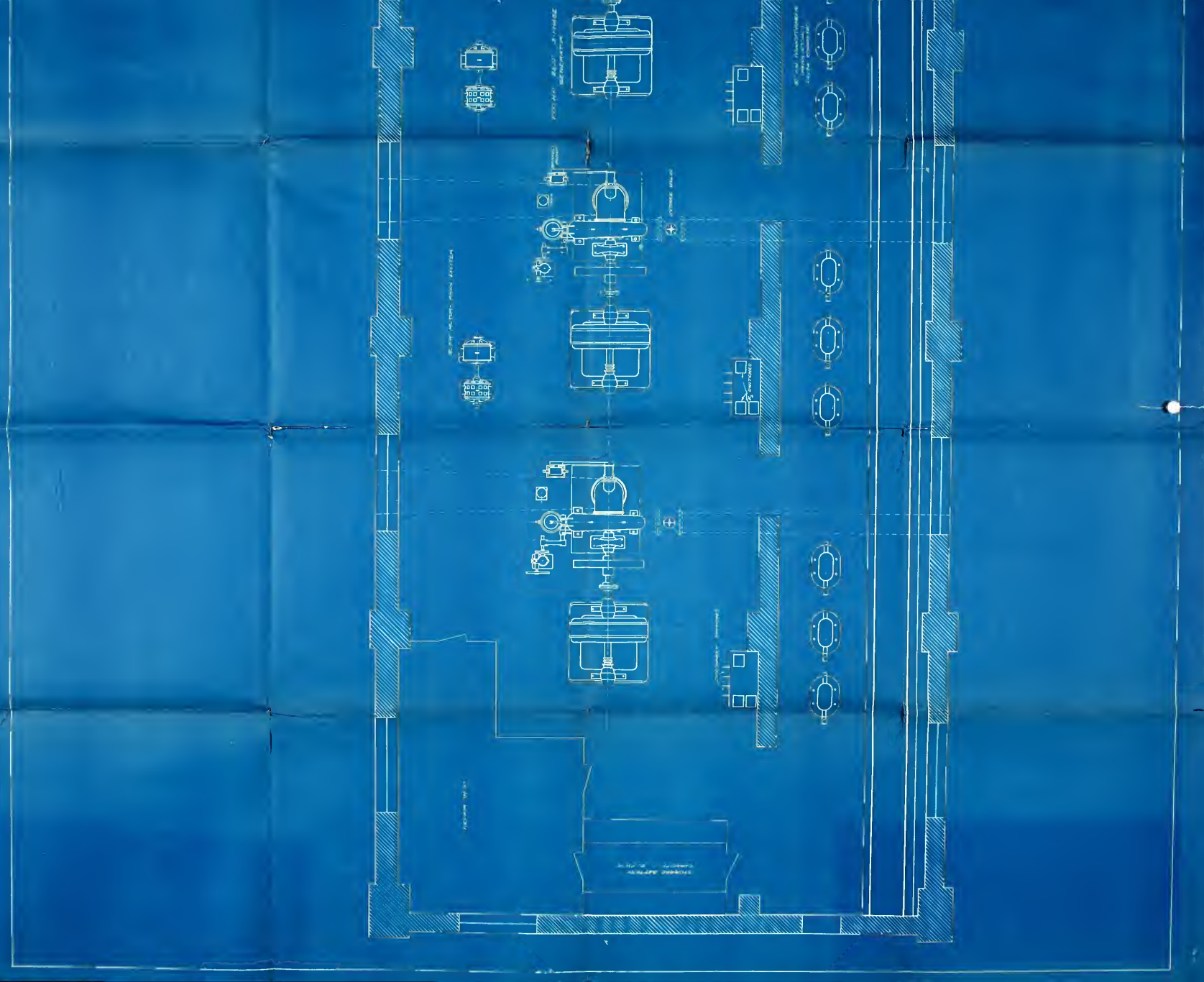
SCALE 1/8"=1'-0"

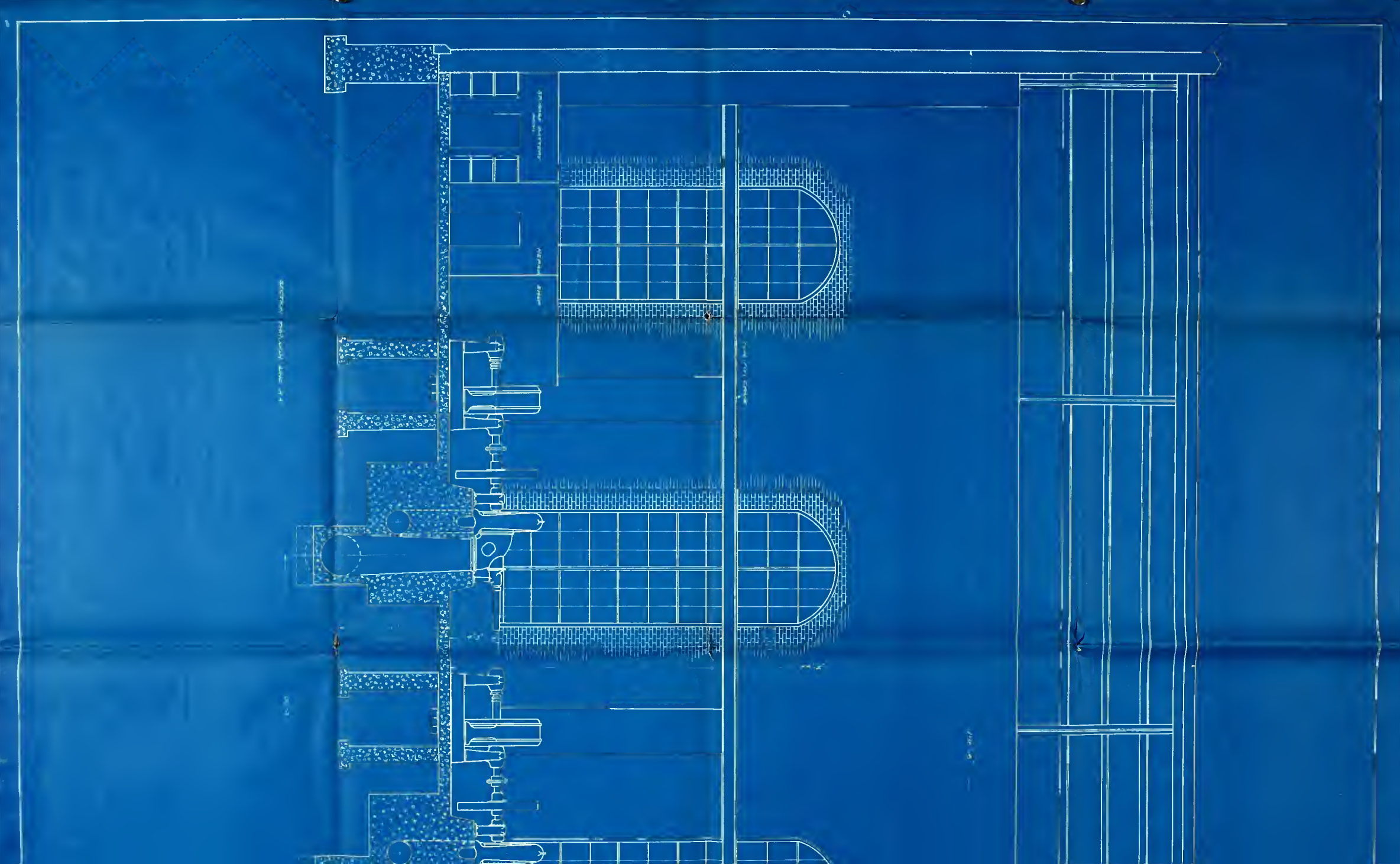
MAY 23, 1910

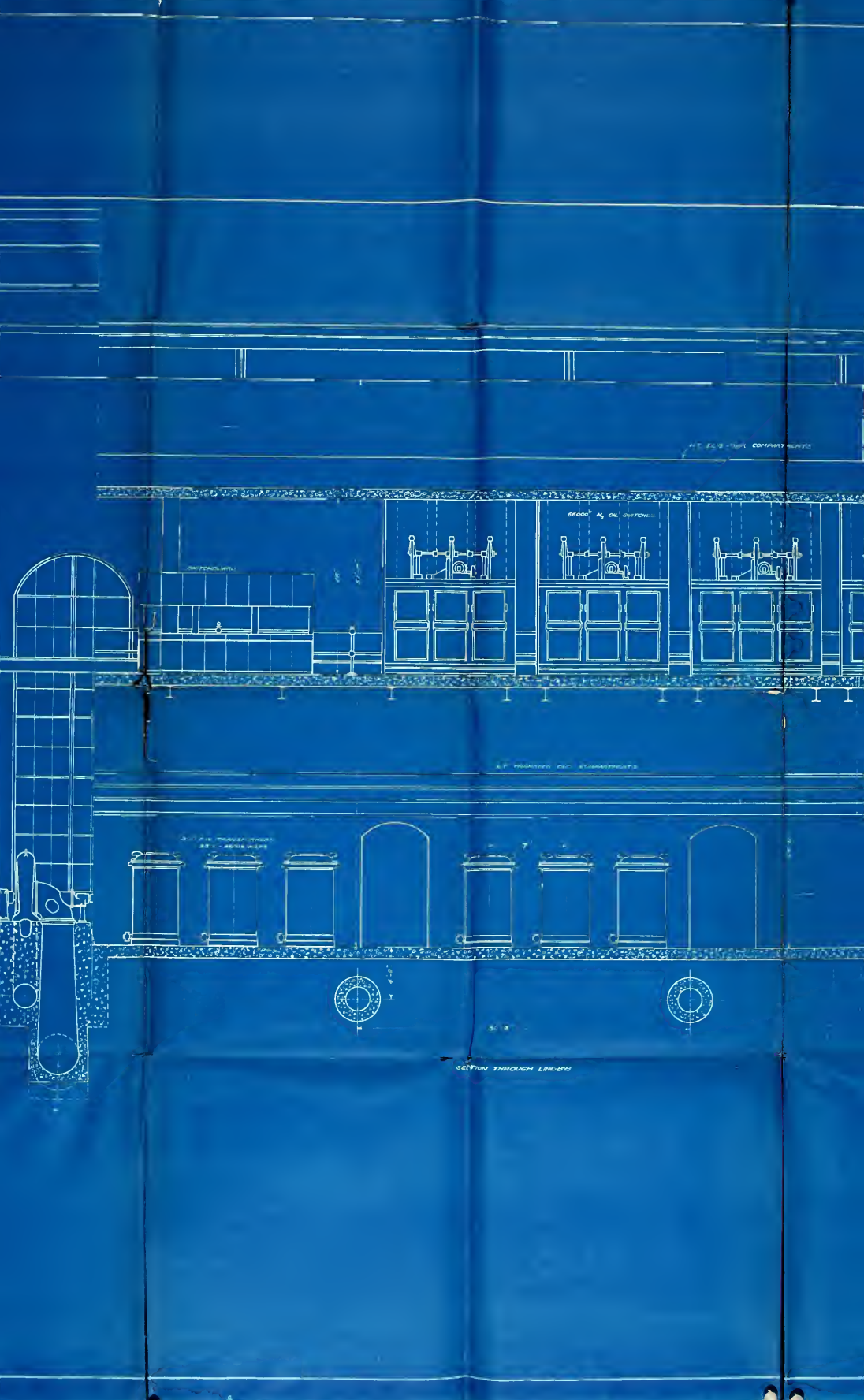
CHICAGO, ILL.

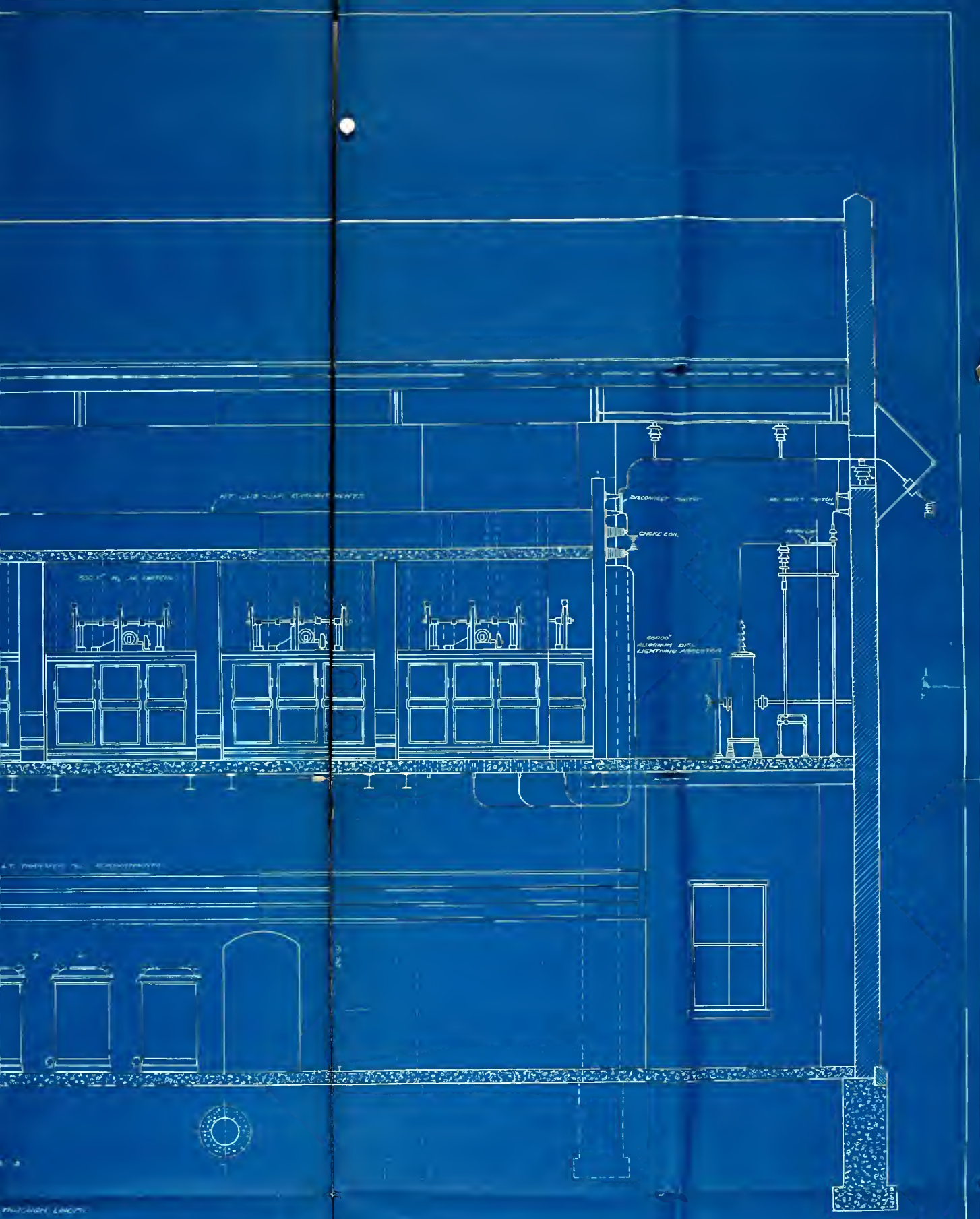


PLAN VIEW
OF
POWER HOUSE
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN AND DESIGNED BY
SCALE 1" = 1'-0"

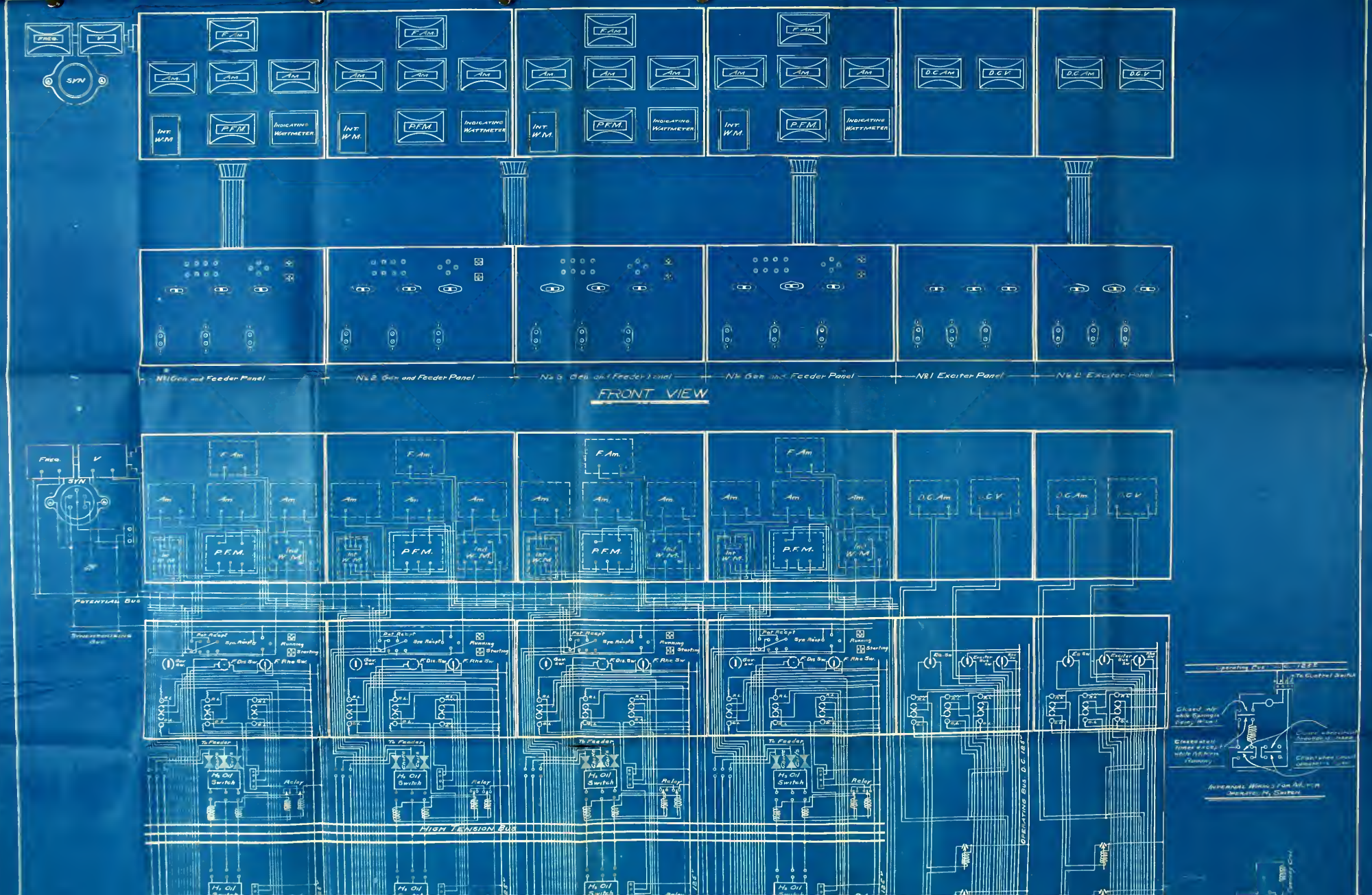


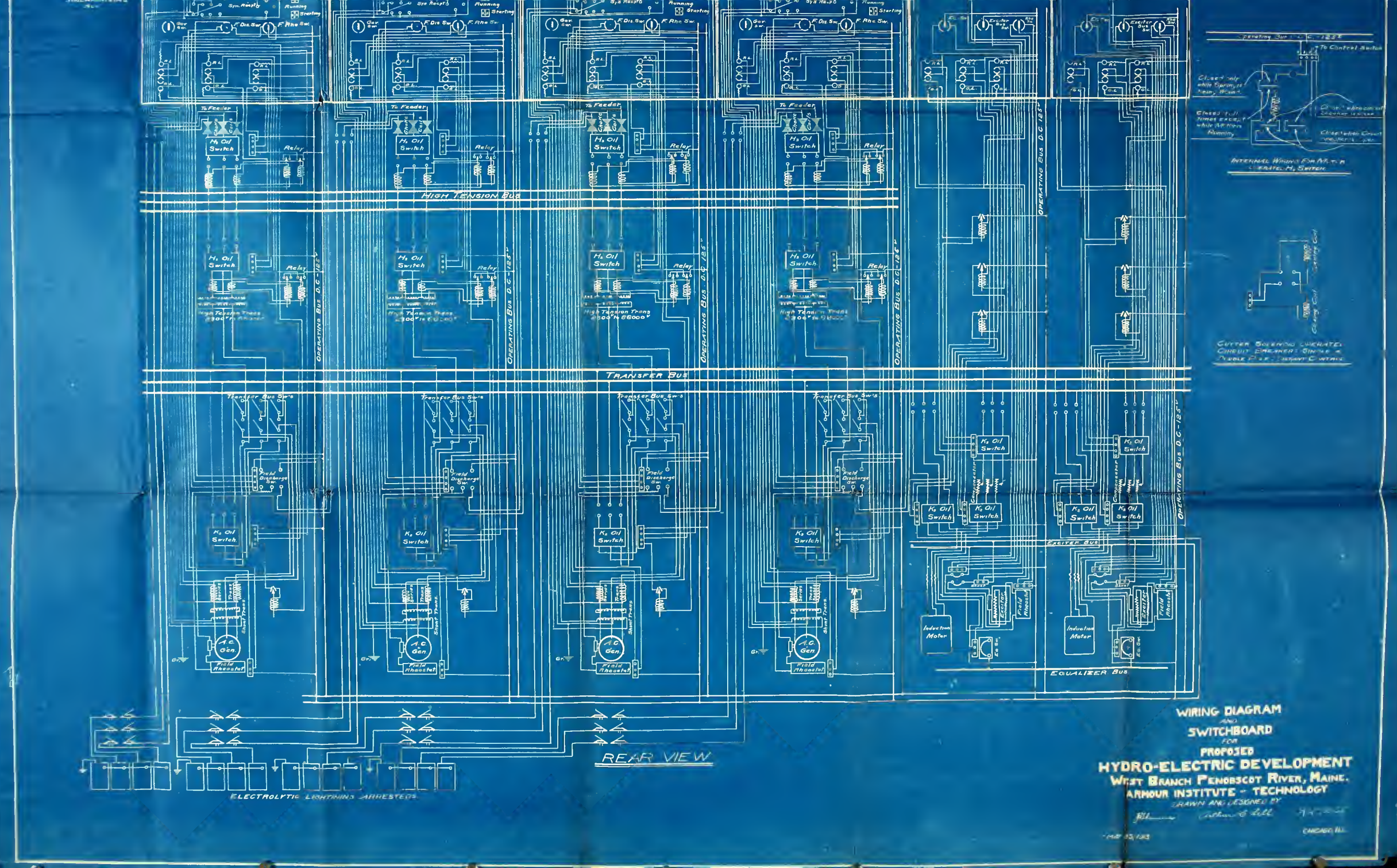



SECTION THROUGH LINE B-B



LONGITUDINAL SECTION
OF
POWER HOUSE
FOR
PROPOSED
HYDRO-ELECTRIC DEVELOPMENT
WEST BRANCH PENOBSCOT RIVER, MAINE.
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN AND DESIGNED BY
[illegible] [illegible] [illegible]
SCALE 1" = 1 FT
MAY 23, 1913
CHICAGO ILL.


FREQ.
V
SYN
F.AM
AM
INT. W.M.
P.F.M.
INDICATING WATTMETER
D.C.AM
D.C.V
No1 Gen and Feeder Panel
No 2 Gen and Feeder Panel
No 3 Gen and Feeder Panel
No 4 Gen and Feeder Panel
No 1 Exciter Panel
No 2 Exciter Panel
FRONT VIEW
POTENTIAL BUS
SYNCHRONIZING BUS
Pot Relays
Syn Relays
Running
Starting
F. Dis. Sw.
F. Rhe. Sw.
To Feeder
H₂ Oil Switch
Relay
HIGH TENSION BUS
OPERATING BUS D.C. 125 V.
Operating Bus
To Control Switch
INTERNAL WIRING FOR ALTERNATOR



WIRING DIAGRAM AND SWITCHBOARD FOR PROPOSED HYDRO-ELECTRIC DEVELOPMENT

WEST BRANCH PENOBSCOT RIVER, MAINE.

ARMOUR INSTITUTE OF TECHNOLOGY

DRAWN AND DESIGNED BY

Arthur G. Lee

CHICAGO, ILL.